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Mathematical Modeling and availability analysis for complex systems of a Sugar Plant using Genetic Algorithm.

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ABSTRACT

In recent years, the availability of process industries has become extremely important issue in most developed and developing countries. The conventional reliability of a system is defined as the probability that a system performs its function properly during a predefined period of time. Availability is a performance criterion for repairable systems that accounts for both the reliability and maintainability aspects of a system. It is defined as the probability that the system is operating properly when it is required for use. The central focus of the present research work is to develop the availability models (under steady state conditions) and to optimize the performance (optimum system availability) of complex systems of a sugar plant. A comprehensive review of the literature is conducted in the field of reliability, availability and availability optimization in process industries. The survey reveals that very little work has been carried out in the quantitative analysis of the real system. Author will try to fill this gap through the present work. In the present work, the mathematical models of various systems in sugar plant will be developed and their availability (performance) will be analyzed. For this purpose simple probabilistic approach and Markov birth model, will be used. The differential equations associated with the systems will be developed. These equations will be solved recursively and reduced to steady state conditions. The steady state availability expressions will be derived, showing the interrelation of states of nature and courses of action for systems of the plant. This will be conducted in the sugar plant -"The Shahabad co-op sugar mills Ltd situated at Shahabad Markanda". The states of nature and courses of action will be recorded for determining their performance level. The system behavior (in operation) will be explained with the help of availability matrix and analyzed in different situations of working environment. The performance optimization (determination of optimum system availability) for sugar plant will be done using the Genetic Algorithm Technique. This technique provides the optimum system availability levels for different combinations of failure and repair rates of the subsystems for improving the performance of the plant concerned.

Key words: Reliability, availability, maintainability, Mathematical model, Markov model

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1. INTRODUCTION

There are various manufacturing processes in which a continuous flow of raw materials through a series of continuous operations takes place and this transforms the raw materials into the final products. Industries producing products like paper, chemicals and sugar etc. during manufacturing need to have such continuous operations. The process industries comprise of large complex engineering units/ subsystems which are arranged in series, parallel or a combination of both. For efficient and economical operation of a process plant, each unit/system/subsystem should run failure free for long duration under the existing operative factory conditions.

All the activities concerning the optimal utilization of man, machine, material and supporting resources must be well organized. Also, these activities are to be coordinated to develop maintenance strategies as it increases productivity and hence profit of the industry. In recent years, automation, rigid production schedules and the need for greater cost-effectiveness have made process industries increasingly aware that maintenance can no longer be considered simply as supporting service to the production process, but must be regarded as an integral part of it, necessitating an effective system of planned maintenance. However, from the study of literature available, it is found that no rigid system for maintenance can be applied universally to all the process industries to accommodate every situation.

Hence, the need of time is to have a suitable maintenance system which must be developed to suit the requirements of a particular process industry, where the raw materials are processed continuously and transformed into the finished products e.g. in case of chemical, paper, sugar, fertilizer and thermal power plants etc. For these industries, the long run availability of each working unit is essential to achieve goal of high production and and utilization to the maximum plant capacity. But, the practical experience is that these units are subjected to random failures which may be restored to original operating state with the help of efficient maintenance system.

Both factory operating conditions and available repair facilities play an important role in analyzing the system failure behavior and maintaining all the equipments in use for maximum span, i.e. repairing the failed equipment and put into operation timely. A detailed system behavioral analysis and a scientific maintenance planning will help a lot in this direction. In

order to express the system availability in quantitative terms, it is necessary to develop performance models for the units/systems and also analyze their maintenance behavior to evaluate the performance in real operating conditions.

In order to express the system availability in quantitative terms, it is necessary to develop performance models for the systems and also analyze their maintenance behavior to evaluate the performance in real operating conditions. It is evident that reliability plays an important role in our daily life. Moreover reliability is an essential part of our morality in social life and in all human activities. On technical side, reliability is the probability that a device will operate as required for a specified time interval. Though the process of achieving reliability involves money, but the achievement of reliability may save money, may have sociological advantages and may prevent the loss of human life. With all practical problems, there is a need to maintain an economic balance between the cost of reliability and the advantages which accrue from its achievement. Thus the question is it reliable? is not enough, we must take into consideration the overall cost. Some of the systems whose reliability is of immediate consequence to the society in general are – power, medical, transportation and communication etc. Hence, reliability appears to be everybody's concern. Unreliable systems are normally associated with high cost, lack of safety, loss of time as well as scarce resources. Unreliable defence equipments would have disastrous effect on the safety of the country and may have adverse effect on the morale of forces. Some of the well known consequences of unreliable engineering systems that brought large scale misery and destruction can be found in recent history. The famous New York Blackout, failures in Apollo and Challenger Missions, Chernobyl Nuclear Power Plant failure and Bhopal Gas Disaster are few of the major events in this category. This needs a thought process.

With the development of human knowledge, the change in technology is taking new dimensions. Human dependence on machines is increasing day by day. The machines and the related equipments used in agriculture, engineering, biology, defence and other disciplines are of utmost importance and necessary for human survival. It is of prime importance and essential that equipment should work in an effective and satisfactory manner under all conditions. A fault or breakdown in the operation of a system may create a very ambiguous situation many times. A weaponry system is approved on the basis of a required military capability without duly considering the other missions which it may or may not be able to

perform. Technological devices used in medical treatment should be accurate and exceptionally be of high standard in respect of their performances.

Reliability of a system (product) conveys the concept of dependability, successful operation or performance and the absence of failures. Reliability is the probability that a machine (product) can perform its intended function, without failure, for a specified interval of time when operating under standard conditions. It should be observed that the above stated definition stresses four significant factors; probability, intended function, time and operating conditions. These four elements play an important role in characterizing the reliability of an item. Product reliability is affected by usage mode, environment and maintenance actions. Quantitatively reliability may be considered as a measure of the success of an engineering system in meeting its stated objectives.

Availability is a performance criterion for repairable systems that accounts for both the reliability and maintainability aspects of a system. It is defined as the probability that the system is operating properly when it is required for use.

Maintainability is defined as the probability of repairing a failed component or system in a specified period of time. Maintenance action can be classified in several categories.

2. LITERATURE REVIEW

The history of modern engineering reflects that system failures usually occur in every field of engineering. Industrial accidents in Union Carbide, Bhopal (1984) and power reactor accident in Chernobyl, USSR (1986) are few worst examples of system failure. The importance of reliability of components, subsystems and systems is also recognized at every stage in daily life, ranging from customer products viz. refrigerators, television sets, cloth washers, dryers and automobiles to large systems such as trains, airlines and process plants.

Development of reliability has strong links with quality control and its development. In early 1920's, statistical methods were developed at Bell Telephone Laboratories, USA, to solve their quality control related problems, which provide them a basis for further developments in the area of statistical quality control. Subsequently, quality control techniques were popularized by American Standard Association and American Society for Mechanical Engineers along with Bell Laboratories. However, the rate of adoption was very slow till the beginning of World War II (1939). The demand for modern technology used in war realized the importance and need of reliability, quality control and decision making. It was reported during World War II that, nearly 60% of the airborne equipments shipped to the Far East

were damaged on arrival and 50% of the spare parts and equipments in storage become unserviceable before being used. In 1949, US navy also reported 70% of their electronic equipments were unserviceable.

In early 1950's reliability engineering has been developed as a separate discipline in USA, to flight with these odd situations. In late 1950's the air force formed an adhoc group on reliability of electronic equipments, whose objective was to recommend the measure to increase the maintenance. In April/June 1951, the US Navy/Army started claborate studies on radio tubes. In 1952, the Department of Defence (DOD), USA, established an Advisory Group on Reliability of Electronic Equipments (AGREE), to coordinate the efforts of the Air Force, Navy and Army. It published its first report on reliability in 1957 which concluded that reliability testing must be made as an integral part of the development of new systems. The new equipments were suggested to be tested for several hours in a high stress environment involving on/off switching, low/high temperatures and steady/vibratory conditions. The idea was to detect most of the design defects at early stage and to rectify them before the start of the production. The report also suggested the procuring agencies to accept the equipment from the manufacturer only after getting the reliability testing certification. The AGREE report was accepted by the DOD and their recommendations became an accepted procedure in all over USA.

In the present scenario of global competition, it has become imperative for all the engineering systems to perform satisfactorily during their expected life span. Due to this fact, almost all developed and developing countries have been shown remarkable progress during last four decades in the application of reliability, availability principles and decision making in various areas.

The literature reflects that several approaches have been adopted to analyse the system availability. The Bayesian approach in the formation of the availability models was used by Brender [1968], Gover [1969] and Thompson [1972]. The Monte Carlo simulation approach was suggested by Faragher and Watson [1964] for the availability analysis of extremely complex systems requiring costly experimentation. The Markovian approach has been frequently used by Barlow, Proschan and Hunt [1965] for the availability analysis, using exponential distribution for failure and repair times. Due to mathematical complexities involved, relatively less work has been done using failure time and repair time distributions other than exponential type distributions.

In general, the determination of availability for the system with elements exhibiting dependent failures and repairs or the operation with standby elements is very complicated and several approaches have been suggested to carry out computations. A system which works well when failure and repair rates are constant can be structured by markov model. While for probability based system, the model is called a markov probability model. The present availability analysis is concerned with a discrete state continuous time model, also called a Markov process.

Nakagawa (1980) gave optimum preventive maintenance policies for repairable systems. M.T.T.F and expected number of preventive maintenance before failure was calculated in the paper. Khan and Gupta (1985**)** have introduced the concept of a pending – failure state in order to consider usual operating and wear out periods of engineering systems and proposed three– state system model. Their important findings were: for a given repair rate the steady state availability of a system can be increased by decreasing the preventive maintenance intervals, and preventive maintenance is more effective for a system having a smaller deterioration factor. Gupta and Tyagi (1986) calculate the availability and M.T.T.F of a standby redundant complex system incorporating the concept of human failure in two states, viz. good and failed. They assumed that single service facility is available for the service of unit failure. Supplementary variable technique & Laplace transformation method was used to obtain various state probabilities. To make the system more applicable to practical life problems, M.T.T.F for the system has also been computed and various graphs were plotted to highlight the utility of the model. Spencer (1986) introduced the concept of duplex systems and evaluated reliability and availability for simple models of duplex systems using Markov methods. All transition rates between states were assumed to be constant.

Many researchers developed and presented various methods for determining optimal maintenance schedules. Zhao (1994) developed a generalized availability model for repairable components and series systems including perfect and imperfect repair. The general distribution was assumed for a repaired component. Thomas F. Hasset (1995) computed time varying failure rate for one component two states & two component four stated configuration. Time varying failure rates were characterized by a general polynomial expression. Markov chain differential equation was used to obtain a hybrid reliability & availability analysis. Schabe (1995) presented a method for obtaining optimum replacement time of a complex system which is subjected to maintenance. Laguerre series expansions were used to compute the availability numerically. Jolly (2001) calculated the reliability parameters such as Mean

time between failures, Mean time to repair, Availability & Maintainability for different machines & described about the design for maintainability. Grall (2002) presented a predictive maintenance structure for a gradually deteriorating single-unit system (continuous time/continuous state). The proposed model was used for optimal inspection & replacement decision in order to balance the cost engaged by failure & unavailability of the system. Kumar K. (2010) presented a mathematical model and analysis of stainless steel utensil manufacturing unit using fuzzy reliability to compute the fuzzy reliability of the stainless steel utensil manufacturing unit for the constant failure and repair rates. The effect of variations of fuzzy reliability with time and system coverage factor for a set of failure and repair rates is also studied. The mathematical model of stainless steel utensil manufacturing unit has been developed using Markov birth – death process.

3. DESCRIPTION OF BROAD AREA/TOPIC

To describe the broad area/topic, it is very important to understand the process of sugar production in which, the cane is usually weighted, washed and chopped in to smaller pieces before the cane is feed to mills (Tandems) for juice extraction.
Juice extraction is mostly done by passing the chopped cane through a series of rollers or horizontal mills. The rollers are laid in a triangle which is supported by a mill housing made of cast iron or cast steel. The prime objective in sugar cane milling is to extract the greatest possible amount of sucrose from sugar cane, and to make the final bagasse as dry as possible so that it will burn readily in the boilers.
Raw sugar cane juice is composed of a great number of organic & inorganic compounds, acids salts etc in varying amounts. When it comes from the mill tandem the juice is an of opaque liquid varying in colour from greenish gray to dark green , it carries suspended matter such as fine bagasse (bagacillo), gums, albumin, wax, coloring matter, particles of soil sand clay and muck. The normal cane juice has pH 5.2-5.4.

The gums, wax and albumin make the raw sugar juice rather viscous and it cannot, therefore be readily filtered when cold. Liming and heating causes many impurities in the juice to become coagulated and precipitated out. At the same time the acids are neutralized and any phosphates present are flocculated, adsorbing a large amount of impurities. Usually the lime is added to the raw sugar cane juice in the form of milk of lime, for better dispersion and quicker reaction. The next process after liming of sugar cane juice is clarification. Without good clarification of

sugar cane juice, the production of good quality raw sugar is impossible. The purpose of clarification is the precipitation and removal of all possible non-sugars (organic & inorganic) and the preservation of the maximum sucrose.

The clarified juice is concentrated to a syrupy consistency before it is sent to the vacuum pans to be crystallized into raw sugar. The concentrate is made in several evaporators connected in series called a multiple effect. The juice travels from one vessel to another because of the gradual increase of vacuum. The vapor obtained in each body of multiple effects serve to heat the tubes and to evaporate additional water in the vessel.

And after being evaporated in a multiple effect evaporator to be a syrupy consistency, clarified juice must be evaporated further for the sugar to crystallize. This is accomplished in a vacuum to form a heavy mixture of crystals and mother liquor, called massecuite. The raw sugar massecuite is then crystallized by cooling. On this process residual syrup incapable of crystallizing called black strap molasses is separated. Finally Batch & continuous centrifugals are used to separate the liquid and hard phases of raw sugar.

The research work will mainly deal with the mathematical modeling and availability analysis of sugar plant located in Shahabad Markanda. The success of any sugar plant depends upon its control and part planning proceeded with their performance and/or production. For this purpose, the mathematical relation will be developed for evaluating the performance of the operating systems in the sugar plant. The expressions for the optimum system's availability are also to be developed. Besides, the effect of some process parameters of such as failure and repair rates of various operating units on the system availability are also to be studied .Moreover, the efforts will also be made for improving the overall availability of the various systems in the sugar plant. Hence the findings of the present research work may be effectively used for the purpose of maintenance decision making and hence to improve the availability and profitability of the process industries. Optimization of system availability will be done by using Genetic Algorithm technique for improving the performance of the sugar plant.

4. OBJECTIVES OF THE STUDY/ PROBLEM IDENTIFICATION

Various objectives of the present study are:

(i) To understand the function of various operating units/subsystems in a sugar production plant

(ii) To develop mathematical models with boundary conditions and solve them by using different techniques.

(iii) To find availability by feeding the data available for each subsystem in mathematical models.

(iv) To conduct in depth availability analysis of various productive units in the sugar industry.

(v) To optimize the system availability by using genetic algorithm technique for improving the performance of the sugar plant.

5. METHODOLOGY TO BE ADOPTED

Since the success of any process industry largely depends upon its process control and planning, therefore, mathematical models are to be developed for evaluating the performance of various operating systems in these process industries. These include the expressions for system's availability affected by failure and repair rates of various operating systems. This will also help in improving the overall availability of various systems in these process industries.

The proposed research work will be carried out in the following order:

(i) Visit and selection of some sugar industries among process industries located in nearby region.

(ii) Study the industrial processes related to sugar industries.

(iii) Study the nature of various subsystems, failure characteristics and running periods etc.

(iv) Study the facilities available for repair of subsystems (maintenance strategies used in sugar industries).

(v) Data collection for each system and test the suitability of the collected data.

(vi) Formulation of the problem in the form of differential equations i.e. development of mathematical models with boundary conditions and solving them by using various techniques.

(vii) Feed the data available for each subsystem in mathematical models developed and find availability for each system.

(viii) Through this, suggestions will be given regarding the importance of equipment/subsystems in the process, critical periods, critical failure and repair times.

(ix) Performance evaluation and optimization of each unit of sugar plant using Genetic Algorithm Technique, which gives the optimum unit availability levels for different combinations of failure and repair rates of the subsystem of each unit of the sugar plant for improving the performance of sugar industry.

6. PROPOSED /EXPECTED OUTCOME OF THE RESEARCH

From the literature review, it is clear that most of the researchers have restricted their work to the development & analysis of theoretical models. These works have little practical significance. Real models for actual plant conditions have been developed by only few researchers. Such researches also have not been able to give any suitable suggestions.

Now in order to fulfill this deficiency, efforts will be made in the present work to develope availability models based on actual situations for sugar production system & hence to find various availability levels.

Beside, the optimum availability of the system will be determined by using GA. It will provide different conditions of failure & repair rates of each subsystems of a particular system of sugar manufacturing plant for improving its performance.

A typical sugar plant consists of various subsystems. The relative importance of each subsystem within the system can be analysed and critical subsystems can also be identified. So the system performance behaviour can be tabulated in the form of availability matrices and analysed further in different situations of working environment. Once the performance level is predicted then it is utilised for finding various feasible courses of action for different systems. So the feasible level of system's performance can be identified for allocating maintenance resources. After allocating of resources for each working system, break even analysis can also help the plant management in deciding the optimum availability level and allocation resources for a desired level of profit.

Then, Performance evaluation and optimization of each unit of sugar plant will be done by using Genetic Algorithm Technique, which will give the optimum unit availability levels for different combinations of failure and repair rates of the subsystem of each unit of the sugar plant for improving the performance of sugar industry.

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